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THE OIL HEATING ASSOCIATION OF CANADA CLEAN AIR PROGRAM PHASE III: EVALUATION OF BURNERS WITH LOW-SPEED MOTORS IN WARM-AIR FURNACES

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THE OIL HEATING ASSOCIATION OF CANADA CLEAN-AIR PROGRAM*

PHASE III: EVALUATION OF BURNERS WITH LOW-SPEED MOTORS IN WARM AIR FURNACES

by

T. D. Brown**

ABSTRACT

Operation of four yellow flame test burners in a refractory lined combustion chamber led invariably to an improved steady state combustion and, generally, to an improved transient state performance compared with that observed when the burners were operated in a stainless steel combustion chamber. Increased nitric oxide emissions attributed to higher flame temperatures were measured in the exhaust from the refractory lined chambers.

Several combinations of burner and firing rate (14 out of 24) could not meet a combustion standard which demands a smoke number less than one and an excess-air level below sixty percent; only one burner performed satisfactorily at all firing rates in both chambers.

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*Prepared for the Equipment and Service Committee of the Oil Heating Association of Canada, Chairman, C. S. James.

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LE PROGRAMME DE L'AIR PROPRE DE L'ASSOCIATION CANADIENNE DE CHAUFFAGE D'HUILE

PHASE III: L'EVALUATION DES BRULEURS AVEC LES MOTEURS DE BAS VITESSE DANS LES FOURNEAUX DE L'AIR CHAUD*

par

T. D. Brown**

RESUME

L'opération de quatre brûleurs d'essai, à flamme jaune, dans une chambre de combustion tapissée de réfractaire a résulté à une combustion améliorée d'état constant et, en général, à une amélioration du rendement d'état transitoire en comparaison des résultats observés lors de l'opération des brûleurs dans une chambre de combustion d'acier. Dans les fumées des chambres avec réfractaires on a mésuré une augmentation des émissions d'oxyde d'azote, attribuée aux températures plus élevées de la flamme.

Plusieurs combinaisons de brûleurs et taux de combustible (14 sur 24) ne pouvaient pas rencontrer un niveau de combustion qui requiert un numéro de fumée inférieur à un et un niveau d'excès d'air inférieur à soixante pourcent; un seul brûleur satisfait tous les taux de combustibles et dans la chambre d'acier et dans la chambre avec réfractaire.

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* Préparé pour le comité de l'equipement et service de l'association canadienne de chauffage d'huile directeur général C. S. James.

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INTRODUCTION

Details of the test equipment and experimental procedures used in the Oil Heating Association Clean Air Program have been described in Mines Branch Investigation Report IR 73-32 entitled: Phase I: Facilities, Techniques and Procedures(1).

In Phase III of the program, tests were done with both warm air furnaces using four burners that were equipped with low-speed (1725 rpm) motors. The results of these tests are given in Appendix A. The discussion is presented in the same order as the data tabulated in Appendix A.

DISCUSSION OF RESULTS: STEADY RUNNING COMBUSTION PERFORMANCE

Combustion Performance at the Standard Draft Condition

TABLE 1

Test Combinations Not Achieving "Low Smoke" Combustion

At the Standard Condition

Furnace	Burner	Firing Rate	Minimum Smoke No.	
Grimsby	Anthes	0.5	8	
		0.75	2	
	Terry	0.5	8	
		0.75	6.5	
		1.00	5	*
	Beckett	0.5	6	
		1.00	3	
Anthes	Beckett	0.5	3/4	
		0.75	3	*

*These measurements were made at the "full open" limit of the air control band. It is possible that the smoke could have been reduced if further adjustment had been possible; this would necessarily have occured at the expense of an excess air level increase.

It should be noted that all steady running measurements quoted in this report were made on burners equipped with a slip clutch.

The test procedure required that the burners were adjusted to a zero smoke number at a "standard" draft condition of minus 0.02 in. water gauge (w.g.). The test combinations at which a zero to one smoke number was not achieved are listed in Table 1.

Only one test burner (the Aero F) performed at a satisfactorily low smoke number in both furnaces at all firing rates. Of the other burners all except one (Beckett: 0.75) performed better in the refractory lined Anthes furnace.

Several burners achieved a satisfactorily low smoke number at the expense of high excess-air combustion as is indicated in Table 2.

TABLE 2

Test Combinations Leading to High Excess Air Combustion

(CO_2 <9%)

Furnace	Burner	Firing Rate	CO_2 Level at Standard Draft (-0.02" w.g.)	Minimum Smoke Number
Grimsby	Anthes	0.5	7.5	8
	Anthes	0.75	8.0	2
	Terry	0.5	7.3	8
	Beckett	0.5	7.4	6
	Beckett	1.00	8.0	3
Anthes	Aero	0.5	8.2	0
	Aero	0.75	6.4	0
	Anthes	0.5	6.6	0
	Terry	0.5	8.3	0
	Beckett	0.5	7.2	3/4
	Beckett	0.75	8.9	3
	Beckett	1.00	7.7	1

The results obtained with the Anthes and Aero burners at 0.75 gph can be compared with previous results obtained in preliminary tests firing a conventional No. 2 fuel oil in the CCRL tunnel furnace and presented to a meeting of the OHA in Ottawa[2].

The improved combustion in the earlier tests with the Anthes burner, where a CO_2 level of 9.5% at a minimum smoke number of 2 was achieved, may be due to the uncooled character of the combustion chamber in that work giving rise to overall higher temperatures.

The improved combustion in the earlier tests with the Aero burner was achieved at the expense of an increased smoke number; the presence of air entrainment around the burner described in IR 73-32[1] may also be responsible for the increase in excess-air level observed in these furnace tests.

Steady state combustion satisfying the dual requirement:

1) medium-excess-air combustion; $CO_2 > 9.0\%$
2) smoke number below 1

has not been met in these tests by the test combinations listed in Table 3.

It should be remembered in considering Table 3 that the only burner recommended for use by the manufacturers at firing rates of 0.5 US gph is the Aero F; and is therefore the only burner that can be expected to perform well at the lowest firing rate.

Combustion Performance Under Modified Draft Conditions

The modified draft conditions were obtained by altering the setting of the barometric chimney damper without changing the burner. The results therefore reflect differences in performance that could be expected under the influence of external wind conditions.

The increased draft condition of -0.07 in. w.g. could not be achieved in one burner/furnace-test combination (Grimsby furnace, Aero Burner at 0.5, 0.75 and 1.00 US gph).

TABLE 3

Inferior Performance Combinations

Furnace	Burner	Firing Rate	Inferior on	
			Excess Air Level	Smoke Number
Grimsby	Anthes	0.5	*	*
	Anthes	0.75	*	*
	Terry	0.5	*	*
	Terry	0.75	*	*
	Terry**	1.00	*	*
	Beckett	0.5	*	*
	Beckett**	1.00	*	*
Anthes	Aero	0.5	*	
	Aero	0.75	*	
	Anthes	0.5	*	
	Terry	0.5	*	
	Beckett	0.5	*	*
	Beckett	0.75	*	*
	Beckett	1.00	*	

**These measurements were made at the "full open" limit of the air control band; reductions in the smoke number due to an increased air flow could only lead to an increase in an already unsatisfactorily high excess-air level.

The reduced draft condition of +0.05 could not be achieved on the Grimsby furnace/Anthes burner combination at 1.00 US gph and the Grimsby furnace/Terry burner combination at 0.5 US gph except at the expense of excessive smoke and carbon monoxide production. These emissions were associated with a decrease in excess-air level.

The modified draft condition of +0.05 could only be achieved in the Anthes furnace with two burners without excessive smoke and carbon monoxide production. These burners were the Terry at 1.00 US gph and the Beckett at 1.00 US gph. To obtain satisfactory results showing the effect of chimney draft on mass flow rate the positive draft test condition was modified to +0.025 and testing continued. Under this condition the burners generally showed an increase in smoke number to levels within the Bacharach scale.

The changes in excess air level due to changes in the chimney draft condition have been calculated as a percentage change in air flow through the burner per 0.01 in. water gauge change in chimney draft to characterize the stability of the burner/furnace combinations.

TABLE 4

The Effect of Chimney Draft on Burner Air Flow Rate

Burner	Firing Rate US gph	% Change in Burner Air Flow per 0.01 Change in Chimney Draft			
		Grimsby Furnace		Anthes Furnace	
		Change to -0.07	Change to +0.07	Change to -0.07	Change to+0.
Aero	0.5	1.51	1.01	1.5	7.0
	0.75	6.9	0.6	1.2	10.6
	1.00	1.4	3.45	2.2	4.6
Anthes	0.5	12.40	2.8	2.1	1.0
	0.75	0.3	0.9	1.3	2.5
	1.00	1.6	-	2.4	1.1
Terry	0.5	1.1	-	3.4	0.4
	0.75	5.7	2.6	0.2	1.4
	1.00	3.1	1.8	0.6	2.7
Beckett	0.5	2.0	0.4	3.5	0
	0.75	0.9	0.7	11.1	1.2
	1.00	2.1	2.2	2.4	1.2

These test results do not show the remarkable changes in mass flow through the Anthes furnace due to chimney draft that were observed in the tests on high-speed motor burners[3].

Smoke Production Under Modified Draft Conditions

At the increased draft condition two burners showed an increase in smoke number; (Beckett; 0.5 US gph in Grimsby furnace and Beckett; 1.00 US gph in the Anthes furnace and Anthes, 0.75 US gph in Grimsby furnace). The changes were all less than unit smoke number and are not significant.

At the reduced draft condition several burner/furnace combinations showed an increase in smoke number; in two tests in the Grimsby furnace the excessive smoke led to abandonment of the test. (Anthes burner 1.00 US gph and Terry burner 0.5 US gph). A change in smoke number greater than 0.5 units per 0.01 in. w.g. change in chimney draft was recorded by the following combinations.

Grimsby Furnace;	Aero Burner	1.00 US gph
Grimsby Furnace;	Beckett Burner	1.00 US gph
Anthes Furnace;	Anthes Burner	0.5 US gph

Carbon Monoxide Production Under Modified Draft Conditions

At the standard draft condition (minus 0.02 in. w.g.) four test combinations produced a carbon monoxide concentration greater than 25 ppm.

Grimsby Furnace;	Anthes Burner,	0.5 US gph
	Beckett Burner,	0.5 and 1.00 US gph
Anthes Furnace;	Aero Burner,	1.00 US gph

At the increased draft condition (minus 0.07 in. w.g.) four test combinations (all in the Grimsby furnace) produced a carbon monoxide concentration greater than 25 ppm.

Grimsby Furnace;	Anthes Burner	0.5 US gph
	Terry Burner*	1.00 US gph
	Beckett Burner	0.5 and 1.00 US gph

At the reduced draft condition (+0.05 in. w.g. in Grimsby furnace; +0.025 in. w.g. in the Anthes furnace) six test combinations produced a carbon monoxide concentration greater than 30 ppm.

Grimsby Furnace;	Aero Burner	1.00 US gph*
	Anthes Burner	0.5 US gph
	Beckett Burner	0.5; 0.75 and 1.00 US gph
Anthes Furnace;	Aero Burner	1.00 US gph

The following burner/firing rate combinations showed a tendency to produce carbon monoxide under all draft conditions in the Grimsby furnace.

Anthes Burner	0.5 US gph
Beckett Burner	0.5 and 1.00 US gph

No burner/firing rate combinations consistently produced carbon monoxide in the Anthes furnace. Where carbon monoxide was produced in the Anthes furnace it occured at the highest firing rate (1.00 US gph).

Nitric Oxide Emissions

A plot of the nitric oxide emissions at the standard draft condition showing the best fit curve to all the data is presented in Figure 1.

Grimsby Furnace

Figure 1 shows a general increase in NO emission with firing rate; no significant change in emission was observed due to the change in draft conditions. The emission levels were highest with the Aero and Anthes burners.

Anthes Furnace

Figure 1 shows a general increase in NO emission with firing rate; no significant change in emission was observed due to changes in draft condition. The emission level was highest with the Anthes burner.

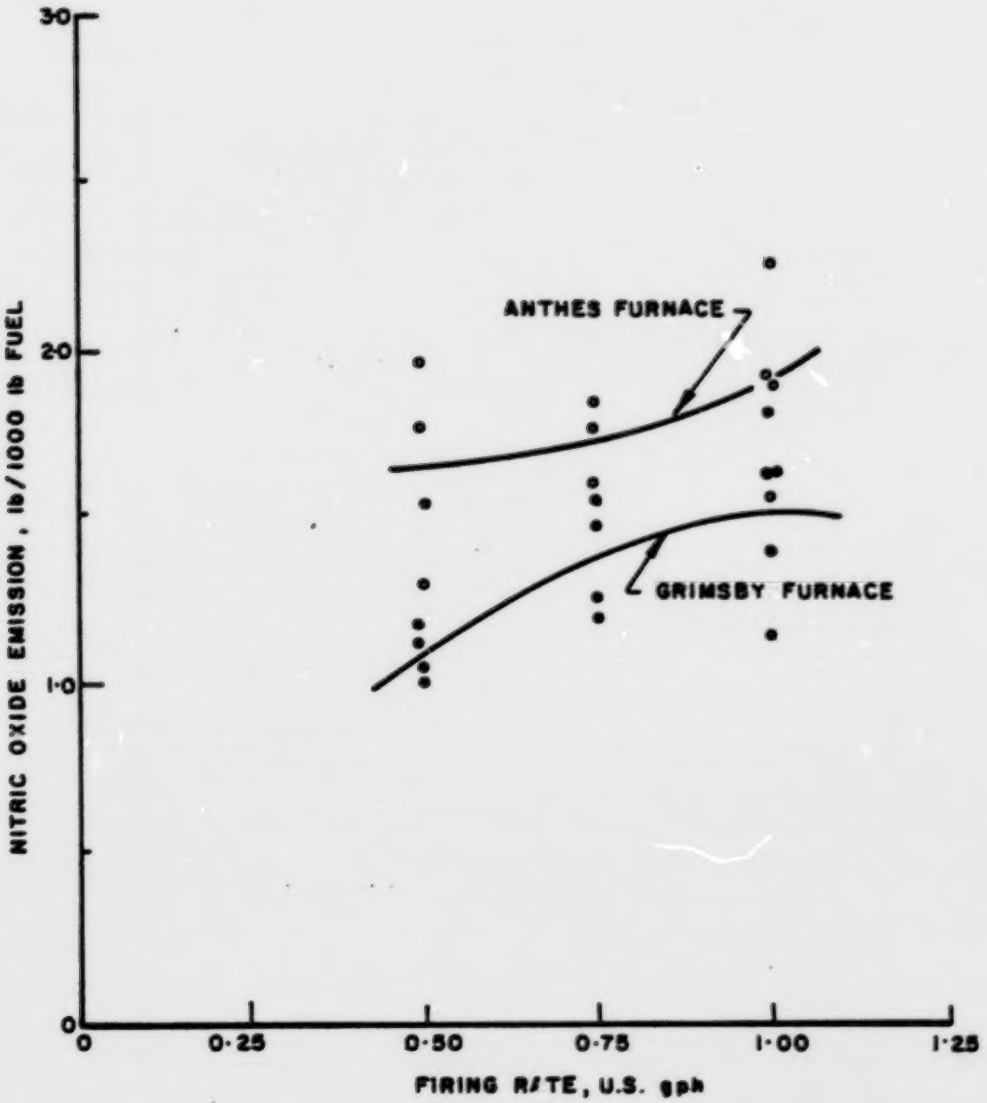

Figure 1. Nitric oxide emission as a function of firing rate.

A statistical comparison of the emissions from the two furnaces again shows that the increased emission from the refractory-lined furnace is highly significant. This was also observed in burner tests with high speed motors[3].

Flue Gas Losses

It can be seen that in Table A5 - A8 for all firing rates, the highest flue gas loss (as measured) occured at the highest draft condition in all but three cases.

The flue gas losses (Tables A9 and A10) have been normalized to standard flue gas temperatures of 300°F and 400°F and the results for the two high-speed motor burners added for comparison purposes. When these normalized results are considered it can be seen that the highest flue gas loss occured when burners were fired at 0.5 US gph with the sole exception of the Beckett.

The best performance was given in the Grimsby furnace by the following burners:

at	0.5 US gph	Aero (1725 rpm)
	0.75 US gph	Aero (1725 rpm)
	1.00 US gph	Aero (3450 rpm) Aero (1725 rpm)

The best performance was given in the Anthes furnace by the following burners:

at	0.5 US gph	Beckett (3450 rpm)
	0.75 US gph	Aero (3450 rpm)
	1.00 US gph	Anthes (1725 rpm)

The Aero (1725 rpm) burner performed better than the Aero (3450 rpm) burner at all firing rates in the Grimsby furnace and worse at all firing rates in the Anthes furnace.

START UP AND SHUT-DOWN COMBUSTION PERFORMANCE

During the start-up and shut-down testing of the burners equipped with low speed motors a continuous smoke meter was available in the laboratory. A discussion of smoke measurement techniques is included in Appendix C.

The Function of Oil-Stop Devices

The steady state evaluation of burners with high and low speed motors was described in an earlier report[3] where it was concluded that the steady state performance did not change with the incorporation of a slip clutch.

The result was not unexpected since the function of a slip clutch is:

1) during start-up to engage the drive to the oil pump when the motor speed reaches its rated value

2) during shut-down to disengage the drive to the oil pump when the motor speed falls below its rated value.

The advantages of a device of this sort are on ignition to prevent oil injection to the furnace until the full combustion air flow is established and on shut-down to stop oil injection whilst combustion air is still entering the furnace thus allowing the dribble of oil into the furnace, due to line pressure in the pump, to occur while combustion air is still being supplied and a flame exists. The use of a solenoid valve in the oil line incorporating a time delay has also been shown to be effective in controlling smoke emissions during start-up and shut-down.

DISCUSSION OF RESULTS: START-UP AND SHUT-DOWN COMBUSTION PERFORMANCE

Smoke Index on Start-Up and Shut-Down

It can be seen in the tabulated results (Tables A13-A16) that:

- in tests without a slip clutch the start-up gave a higher smoke index than the shut-down in 24 out of 54 tests

in tests with a slip clutch the start-up gave a higher smoke index than the shut-down in 45 out of 54 tests

in tests without a slip clutch the burners performed better (i.e. a lower smoke index) or equally well in the Anthes furnace compared to the Grimsby furnace in 24 out of 27 start-up tests and in 20 out of 27 shut-down tests

in tests with a slip clutch the burners performed better (i.e. a lower smoke index) or equally well in the Anthes furnace compared to the Grimsby furnace in 23 out of 27 start-up tests and in 17 out of 27 shut-down tests

in tests on the Grimsby furnace the burners performed better (i.e. a lower smoke index) or equally well with a slip clutch in 22 out of 36 start-up tests and in 29 out of 36 shut-down tests

in tests on the Anthes furnace the burners performed better (i.e. a lower smoke index) or equally well with a slip clutch in 19 out of 27 start-up tests and in 21 out of 27 shut-down tests.

These results indicate that the start-up and shut-down performances of the test burners were generally similar (in terms of soot generation) when operated without slip clutches. The inclusion of a slip clutch improved the start-up performance more than the shut-down performance. A singular exception to the general trend of improvement with slip clutch inclusion was observed with the Terry burner in the Grimsby furnace which performed worse with a slip clutch in eight out of nine start-up tests.

The improved performance of the burners in the Anthes furnace can be attributed to the high temperature of the refractory lining in the combustion chamber assisting combustion of the oil "dribble" after shut-down. This will reduce soot emission on shut-down and reduce the deposition of soot within the system. Subsequent ignitions will not detach soot from furnace surfaces and the start-up smoke index will be due to soot from the flame alone rather than a composite quantity of flame soot plus deposited soot.

The investigation of pump performance showed that the 1725 rpm pumps do not have significantly different start-up characteristics; one pump (originally on the Anthes burner) gave a much better shut-down performance. This was not reflected in the furnace tests.

Peak Carbon Monoxide Concentrations on Start-Up and Shut-Down

It can be seen in the tabulated results (Tables A18, A19 and A20) that:

in tests without a slip clutch the burners performed better (i.e. a lower peak carbon monoxide concentration) or equally well in the Anthes furnace in all start-up tests and in 18 out of 27 shut-down tests. The margin of improvement was usually small.

in tests with a slip clutch the burners performed equally in both furnaces in 15 out of 27 start-up tests and in all shut-down tests. In six start-up tests the Terry burner performed better in the Anthes furnace whereas in three start-up tests the Anthes burner performed better in the Grimsby furnace

in tests on the Grimsby furnace the burners performed better or equally well with a slip clutch in 20 out of 27 start-up tests and in 24 out of 27 tests

in tests on the Anthes furnace the burners performed better of equally well with a slip clutch in 24 out of 27 start-up tests and in all shut-down tests.

CONCLUSIONS

Steady Running Combustion Performance

1. Only one burner (the Aero 1725 rpm) performed at a satisfactorily low smoke number in both furnaces at all firing rates.

2. All burner/firing rate combinations (except 1: see page 2) performed at lower smoke numbers in the refractory lined furnace.

3. Fourteen burner/firing rate combinations (out of 24)could not meet a combined standard of 0-1 smoke number and <9% CO_2.

4. The nitric oxide emission from the test burners increased with firing rate in both furnaces. The increased emission from the refractory lined furnace compared to that from the stainless steel lined furnace was statistically significant.

Start-Up and Shut-Down Combustion Performance

In conclusions 5, 6 and 7 the term "better" means a lower smoke index.

5. The shut-down performance of the burners tested was generally better than the start-up performance.

6. The start-up and shut-down performance of the Aero, Anthes and Beckett burners was improved by the inclusion of a slip clutch.

7. The start-up and shut-down performance of the burners tested was better in the refractory lined Anthes furnace than in the stainless steel Grimsby furnace.

In conclusions 8 and 9 the term "better" means a lower peak carbon monoxide concentration.

8. In a majority of cases the burners performed better in the Anthes furnace than in the Grimsby furnace. The margin of improvement was small.

9. The introduction of a slip clutch improved the performance of the burners in both furnaces, the margin of improvement was greater in the Anthes furnace.

REFERENCES

1. The Oil Heating Association of Canada Clean Air Program: Phase I: Facilities, Techniques and Procedures, Mines Branch Investigation Report IR 73-32, Department of Energy, Mines and Resources, Ottawa, Canada.

2. Some Performance Characteristics of Flame Retention-Head Domestic Burners, Divisional Report FRC 72/8, Fuels Research Centre, Mines Branch, Department of Energy,Mines and Resources, Ottawa, Canada.

3. The Oil Heating Association of Canada Clean Air Program: Phase II: Evaluation of Burners with High-Speed Motors in Warm Air Furnaces, Mines Branch Investigation Report IR 73-33, Department of Energy, Mines and Resources, Ottawa, Canada.

APPENDIX A: TABULATION OF TEST DATA

TABLE A1

STEADY RUNNING PERFORMANCE

Grimsby Furnace - Slip Clutch

Burner	Nozzle US gph	Draft Inch wg	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Aero	0.5	+0.08	10.4	7.4	0	<6	0
		-0.02	9.3	8.6	0	"	0-1
		-0.04	9.0	9.0	0	"	0
	0.75	+0.05	12.0	5.5	<20	"	3
		-0.02	11.5	6.1	<20	"	0-1
		-0.55	9.2	8.8	20	"	0
	1.00	+0.045	13.6	3.3	30	"	7
		-0.02	10.5	7.3	<20	"	0
		-0.055	10.0	7.9	<20	"	0
Anthes	0.5	+0.03	9.0	9	400	"	9
		-0.02	7.5	10.8	1100	"	8
		-0.075	2.2	17.5	300	"	7
	0.75	+0.08	8.9	8	<20	0	4
		-0.02	8	9.5	<20	0	2
		-0.09	7.8	9.8	<20	0	2
	1.00	+0.01	Test discontinued, excessive pulsation and smoke.				
		-0.02	10.3		5.8	0	1
		-0.09	9.2		7	<20	0

TABLE A2

STEADY RUNNING PERFORMANCE

Grimsby Furnace - Slip Clutch

Burner	Nozzle US gph	Draft Inch wg	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Terry	0.5	+0.05	Test discontinued, excessive smoke.				
		-0.02	7.3	10.65	0	-	8
		-0.07	7.9	10.4	0	-	8.2
	0.75	+0.05	8.3	9.2	0	<6	2
		-0.02	10	5.6	0	"	6.5
		-0.07	7.6	10	0	"	1
	1.00	+0.05	11	5.75	<20	<6	8
		-0.02	9.55	7.1	0	"	5
		-0.07	8.1	9.3	25	"	3
Beckett	0.5	+0.05	7.1	11.3	1000	6	5
		-0.02	7.4	11	700	-	6
		-0.085	6.2	12	350	-	7
	0.75	+0.05	9.6	8.0	50	-	1
		-0.02	9.1	8.6	20	<6	0
		-0.07	8.6	9.0	20	<6	0
	1.00	+0.05	9.7	7.5	100	<6	8
		-0.02*	8	9.8	300	<6	3
		-0.08	6.8	10.7	400	<6	1-2

*Air control band fully open.

TABLE A3

STEADY RUNNING PERFORMANCE

Anthes Furnace - Slip Clutch

Burner	Nozzle US gph	Draft Inch wg	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Aero	0.5	0.015	11.1	6.6	< 20	0	1
		-0.02	8.2	9.8	-	0	0
		-0.055	7.6	10.3	< 20	0	0
	0.75	+0.02	12.1	5.3	-	-	0
		-0.02	6.4	9.9	< 20	0	0
		-0.05	6.0	10.7	< 20	0	0
	1.00	+0.03	13.0	-	170	<6	2
		-0.02	10.0	-	160	<6	0
		-0.065	9.0	-	160	<6	0
Anthes	0.5	+0.03	7.1	10.9	0	-	3
		-0.02	6.6	11.0	< 20	-	0
		-0.65	5.7	12.1	20	-	0
	0.75	+0.02	10.3	5.8	0	<6	0
		-0.02	9.2	7.5	< 20	-	0
		-0.07	9.9	7.5	< 20	-	1
	1.00	+0.04	12.2	4.5	< 20	-	1
		-0.02	10.8	5.9	0	-	0
		-0.08	9.4	7.5	0	-	0

TABLE A4

STEADY RUNNING PERFORMANCE

Anthes Furnace - Slip Clutch

Burner	Nozzle US gph	Draft Inch wg	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Terry	0.5	+ 0.015	8.15	9.8	0	-	0
		- 0.02	8.3	9.7	0	-	0
		- 0.065	6.9	11.0	0	-	0
	0.75	+ 0.015	9.9	8.0	0	-	0
		- 0.02	9.4	8.5	0	-	< 1
		- 0.07	9.5	8.4	0	-	< 1
	1.00	+ 0.05	11.6	6.0	0	-	1
		- 0.02	9.35	8.6	0	-	0
		- 0.075	9.7	8.2	0	-	0
Beckett	0.5	+ 0.04	7.2	10.4	0	-	2
		- 0.02	7.2	10.9	< 20	-	3-4
		- 0.07	5.6	12.8	< 20	-	3
	0.75	+ 0.04	8.2	9	0	-	0
		- 0.02	8.9	8.2	0	-	3
		- 0.04	6.9	11.1	0	-	1
	1.00	+ 0.07	8.8	7.8	0	-	4
		- 0.02	7.7	9.7	0	-	1
		- 0.07	6.6	10.8	0	-	2

TABLE A5

STEADY RUNNING PERFORMANCE

Grimsby Furnace - Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wg	Flue Gas Loss %	Flue Gas Temperature °F
Aero	0.5	+0.05	12.59	310
		-0.02	12.62	288
		-0.07	12.34	273
	0.75	+0.05	13.06	362
		-0.02	13.8	380
		-0.07	16.28	403
	1.00	+0.05	11.39	320
		-0.02	15.64	422
		-0.07	17.06	456
Anthes	0.5	+0.05	13.75	317
		-0.02	16.65	356
		-0.07	35.22	312
	0.75	+0.05	17.54	432
		-0.02	19.66	458
		-0.07	20.06	460
	1.00	+0.05	16.65	452
		-0.02	18.21	525
		-0.07	20.05	552

TABLE A6

STEADY RUNNING PERFORMANCE

Grimsby Furnace - Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wg	Flue Gas Loss %	Flue Gas Temperature °F
Terry	0.5	+0.05	-	-
		-0.02	15.22	312
		-0.07	12.97	268
	0.75	+0.05	17.21	400
		-0.02	15.15	390
		-0.07	19.36	432
	1.00	+0.05	15.9	447
		-0.02	18.36	483
		-0.07	21.69	520
Beckett	0.5	+0.05	16.46	337
		-0.02	16.02	336
		-0.07	17.43	327
	0.75	+0.05	15.68	396
		-0.02	16.17	422
		-0.07	17.78	428
	1.00	+0.05	18.39	490
		-0.02	22.59	540
		-0.07	25.73	550

TABLE A7

STEADY RUNNING PERFORMANCE

Anthes Furnace - Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wg	Flue Gas Loss %	Flue Gas Temperature °F
Aero	0.5	+0.05	13.53	360
		-0.02	17.68	410
		-0.07	19.50	440
	0.75	+0.05	14.72	432
		-0.02	24.34	492
		-0.07	26.80	520
	1.00	+0.05	14.24	435
		-0.02	18.57	508
		-0.07	21.51	560
Anthes	0.5	+0.05	18.77	390
		-0.02	19.80	398
		-0.07	23.08	423
	0.75	+0.05	16.31	440
		-0.02	18.07	460
		-0.07	17.28	460
	1.00	+0.05	15.33	460
		-0.02	19.12	560
		-0.07	22.13	600

TABLE A8

STEADY RUNNING PERFORMANCE

Anthes Furnace - Flue Gas Losses

Burner	Firing Rate US gph	Nominal Draft Inch wg	Flue Gas Loss %	Flue Gas Temperature °F
Terry	0.5	+0.05	17.57	405
		-0.02	17.55	410
		-0.07	20.55	430
	0.75	+0.05	18.30	495
		-0.02	19.21	505
		-0.07	18.96	510
	1.00	+0.05	17.03	510
		-0.02	19.80	522
		-0.07	21.37	590
Beckett	0.5	+0.05	18.95	404
		-0.02	19.19	410
		-0.07	23.72	430
	0.75	+0.05	19.08	450
		-0.02	19.41	490
		-0.07	22.43	476
	1.00	+0.05	21.18	540
		-0.02	22.93	533
		-0.07	26.29	550

TABLE A9

Comparison of Burner/Furnace Efficiencies at Constant Flue Gas Temperatures

Grimsby Furnace

(All at Standard - 0.02 Draft)

Burner	Nozzle US gph	Flue Gas Loss % Flue Gas Temperature	
		300°F	400°F
Aero 1725-rpm Motor	0.5	12.99	16.09
	0.75	11.76	14.31
	1.00	12.25	15.03
Anthes 1725-rpm Motor	0.5	14.53	18.32
	0.75	14.03	17.6
	1.00	12.36	15.19
Terry 1725-rpm Motor	0.5	14.75	18.63
	0.75	12.54	15.44
	1.00	12.82	15.84
Beckett 1725-rpm Motor	0.5	14.64	18.47
	0.75	13.13	16.29
	1.00	14.03	17.6
Aero 3450-rpm Motor	0.5	14.22	17.87
	0.75	12.15	14.87
	1.00	12.25	15.03
Beckett 3450-rpm Motor	0.5	14.86	18.80
	0.75	12.09	14.80
	1.00	12.31	15.11

TABLE A10

Comparison of Burner/Furnace Efficiencies at Constant Flue Gas Temperatures

Anthes Furnace

(All at Standard - 0.02 Draft)

Burner	Nozzle US gph	Flue Gas Loss % Flue Gas Temperature	
		300°F	400°F
Aero 1725-rpm Motor	0.5	13.85	17.33
	0.75	15.9	20.30
	1.00	12.54	15.44
Anthes 1725-rpm Motor	0.5	15.62	19.89
	0.75	13.06	16.19
	1.00	12.09	14.8
Terry 1725-rpm Motor	0.5	13.76	17.21
	0.75	12.92	15.99
	1.00	12.95	16.04
Beckett 1725-rpm Motor	0.5	14.86	18.80
	0.75	13.20	16.51
	1.00	14.32	18.02
Aero 3450-rpm Motor	0.5	15.76	20.09
	0.75	12.60	15.52
	1.00	12.60	15.52
Beckett 3450-rpm Motor	0.5	12.92	15.99
	0.75	13.20	16.4
	1.00	12.15	14.87

TABLE A11

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions - Grimsby Furnace

Burner	Nozzle US gph	Nominal Draft Inch wg	Nitric Oxide Emissions	
			ppm	lb/1000 lb Fuel
Aero	0.5	+0.05	55	1.27
		-0.02	45	1.15
		-0.07	47	1.24
	0.75	+0.05	75	1.51
		-0.02	70	1.47
		-0.07	60	1.55
	1.00	+0.05	87	1.57
		-0.02	80	1.83
		-0.07	76	1.82
Anthes	0.5	+0.05	48	1.26
		-0.02	36	1.09
		-0.07	-	-
	0.75	+0.05	42	1.12
		-0.02	54	1.56
		-0.07	54	1.59
	1.00	+0.05	-	Discontinued
		-0.02	68	1.59
		-0.07	64	1.65
Terry	0.5	+0.05	-	Discontinued
		-0.02	36	1.11
		-0.07	33	.96
	0.75	+0.05	53	1.48
		-0.02	50	1.20
		-0.07	46	1.46
	1.00	+0.05	48	1.05
		-0.02	46	1.15
		-0.07	-	-
Beckett	0.5	+0.05	48	1.51
		-0.02	36	1.01
		-0.07	36	1.23
	0.75	+0.05	49	1.21
		-0.02	48	1.25
		-0.07	47	1.28
	1.00	+0.05	44	1.28
		-0.02	48	1.39
		-0.07	41	1.33

TABLE A12

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions - Anthes Furnace

Burner	Nozzle US gph	Nominal Draft Inch wg	Nitric Oxide Emissions	
			ppm	lb/1000 Fuel
Aero	0.5	+0.05	96	2.09
		-0.02	70	1.98
		-0.07	65	1.93
	0.75	+0.05	-	-
		-0.02	-	-
		-0.07	-	-
	1.00	+0.05	-	-
		-0.02	-	-
		-0.07	-	-
Anthes	0.5	+0.05	58	1.82
		-0.02	54	1.78
		-0.07	52	1.86
	0.75	+0.05	94	2.19
		-0.02	70	1.81
		-0.07	77	1.86
	1.00	+0.05	115	2.29
		-0.02	102	2.27
		-0.07	85	2.15
Terry	0.5	+0.05	61	1.73
		-0.02	55	1.55
		-0.07	-	-
	0.75	+0.05	72	1.74
		-0.02	71	1.80
		-0.07	72	1.81
	1.00	+0.05	78	1.63
		-0.02	75	1.91
		-0.07	73	1.80
Beckett	0.5	+0.05	46	1.43
		-0.02	42	1.31
		-0.07	52	1.89
	0.75	+0.05	64	1.81
		-0.02	60	1.62
		-0.07	54	1.73
	1.00	+0.05	58	1.55
		-0.02	53	1.58
		-0.07	50	1.65

TABLE A13

START-UP AND SHUT-DOWN PERFORMANCE

Aero Burner

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Smoke Index			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Aero 1725 rpm Motor	Grimsby	0.5	- .02	3.2	10.7	2.1	0
			- .05	3.0	8.9	1.1	0
			+ .05	4.7	11.7	2.4	0
		0.75	- .02	3.3	11.5	1.3	0.
			- .05	3.5	9.9	1.6	0
			+ .05	2.9	10.7	2.2	1.69
		1.00	- .02	7.7	5.5	2.1	0.45
			- .05	4.6	3.98	2.3	0
			+ .05	11.9	11.5	7.6	4.96
	Anthes	0.5	- .02	2.3	3.7	0.9	0.9
			- .05	3.0	3.4	1.4	0
			+ .05	2.9	9.2	3.0	0.6
		0.75	- .02	2.3	3.9	0.6	0
			- .05	1.8	2.0	0.7	0
			+ .05	2.4	7.4	1.0	0
		1.00	- .02	1.3	5.6	0.5	3.4
			+ .05	1.5	1.4	1.3	0
			+ .05	1.9	8.2	3.8	0

TABLE A14

START-UP AND SHUT-DOWN PERFORMANCE

Terry Burner

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Smoke Index			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Terry (standard) 1725 rpm Motor	Grimsby	0.5	- .02	3.1	2.4	13.3	8.5
			- .08	3.1	1.7	12.7	7.3
			- .05	4.7	4.3	8.1	13.8
		0.75	- .02	2.9	2.2	3.1	2.8
			- .07	2.5	1.0	2.0	1.4
			+ .05	4.1	5.6	7.3	4.9
		1.00	- .02	6.0	5.1	7.5	2.7
			- .07	4.5	2.3	7.8	2.0
			+ .05	7.4	6.2	10.7	4.8
	Anthes	0.5	- .02	2.6	2.6	0.6	0
			- .05	2.8	1.8	0.8	0
			+ .05	3.2	6.5	1.5	0
		0.75	- .02	1.5	1.9	0.7	0
			- .05	1.9	0.9	1.3	0
			+ .05	2.3	3.0	1.8	0
		1.00	- .02	1.4	2.1	1.3	0
			- .05	1.7	1.3	1.2	0
			+ .05	1.5	1.9	7.9	2.75

TABLE A15

START-UP AND SHUT-DOWN PERFORMANCE

Anthes Burner

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Smoke Index			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Anthes	Grimsby	0.50	- .02	6.7	5.5	2.4	0
			- .07	6.27	3.99	4.5	2.50
			+ .05	12.0	12.9	6.14	3.20
		0.75	- .02	3.97	2.66	3.97	2.66
			- .07	2.83	0.99	2.83	0
			+ .05	8.87	2.43	8.8	2.4
		1.00	- .02	2.44	4.65	2.7	0
			- .07	2.26	3.21	4.0	2.5
			+ .05	2.6	8.28	3.4	1.5
	Anthes	0.50	- .02	2.1	3.9	1.9	0
			- .07	2.4	3.0	3.0	0
			+ .05	2.4	2.3	3.0	3.2
		0.75	- .02	2.1	3.9	1.9	2.9
			- .07	2.4	3.0	3.0	3.0
			+ .05	2.4	2.3	3.0	3.2
		1.00	- .02	1.8	0.82	1.6	3.6
			- .07	1.9	0.5	1.9	2.8
			+ .05	2.8	0.5	3.5	2.5

TABLE A16

START-UP AND SHUT-DOWN PERFORMANCE

Beckett S

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Smoke Index			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Beckett S	Grimsby	0.5	- .02	10.4	5.4	11.5	3.9
			- .07	13.7	5.9	6.4	2.7
			+ .05	19.2	13.4	10.4	5.4
		0.75	- .02	5.25	3.6	8.8	6.7
			- .07	2.8	1.71	3.4	1.5
			+ .05	8.91	5.87	11.6	6.6
		1.00	- .02	7.7	5.7	7.5	2.9
			- .07	4.8	3.5	3.6	1.4
			+ .05	11.7	8.5	11.3	6.0
	Anthes	0.5	- .02				
			- .07				
			+ .05				
		0.75	- .02				
			-. 07				
			+ .05				
		1.00	- .02				
			- .07				
			+ .05				

TABLE A17

START-UP AND SHUTDOWN PERFORMANCE

Pumps

Pump		Smoke Index	
		Start-Up	Shut-Down
Aero	1725 rpm motor	2.0	3.5
Anthes	1725 rpm motor	2.05	0
Terry	1725 rpm motor	3.15	3.57
Beckett	3450 rpm motor	0.5	2.9
Aero	3450 rpm motor	1.5	8.8

*The 1725 rpm pumps were tested using the Terry burner in the Grimsby furnace adjusted to 9% CO_2 at the standard draft condition of - 0.02 in. wg without a slip clutch at the firing rate of 0.75 US gph.

The 3450 rpm pumps were tested using the Aero burner in the Grimsby furnace, firing rate at 0.75 US gph adjusted to 9% CO_2 at the standard draft condition of 0.02 in. wg without a slip clutch.

TABLE A18

START-UP and SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Peak Carbon Monoxide %			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Terry	Grimsby	0.5	- .02	.06	0		trace
			- .07	.075	0		.02
			+ .05	.08	0		0
		0.75	- .02	0.01	0	0.02	0
			- .07	0.02	0	trace	0
			+ .05	0.01	0	0.02	0
		1.00	- .02	.01	0	trace	0
			- .07	.01	0	trace	0
			+ .05	0.005	0	trace	0
	Anthes	0.5	- .02	0	0	0	0
			- .07	0	0	0	0
			+ .05	0	0	0	0
		0.75	- .02	0	0	0	0
			- .07	0	0	0	0
			+ .05	0	0	0	0
		1.00	- .02	0	0	0	0
			- .07	0	0	0	0
			+ .05	0	0	0	0

TABLE A19

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Peak Carbon Monoxide ppm			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Aero	Grimsby	0.5	- .02	-	0.05	0	0
			- .07	-	0.02	0	0
			+ .05	-	0.05	0	0
		0.75	- .02	-	0.03	0	0
			- .07	-	0.01	0	0
			+ .05	-	0.12	0	0
		1.00	- .02	-	0.0	0	0
			- .07	-	0.0	0	0
			+ .05	-	0.18	0	0
	Anthes	0.05	- .02	0	0.12	0	0
			- .07	0	0.05	0	0
			+ .05	trace	0.11	0	0
		0.75	- .02	0	0	0	0
			- .07	0	0.01	0	0
			+ .05	0	0.07	0	0
		1.00	- .02	0	0.06	0	0
			- .07	0	0.08	0	0
			+ .05	trace	0.11	0	0

TABLE A20

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Furnace	Firing Rate US gph	Nominal Draft Inch wg	Peak Carbon Monoxide %			
				Without Slip Clutch		With Slip Clutch	
				Start Up	Shut Down	Start Up	Shut Down
Anthes	Grimsby	0.5	- .02	0.16	0	0.30	0
			- .07	0.11	0	0.28	0
			+ .05	0.20	0	0.27	0
		0.75	- .02	0.09	0	0.03	0
			- .07	0.08	0	0.045	0
			+ .05	-	0	trace	0
		1.00	- .02	0.05	.05	0	0
			- .07	trace	0	0	0
			+ .05	0.44	0.44	0	0
	Anthes	0.5	- .02	0	0.09	0.04	0
			- .07	0.02	0.15	0.14	0
			+ .05	0	0.03	0.03	0
		0.75	- .02	0	0.09	0.04	0
			- .07	0	0	0	0
			+ .05	0	0	0	0
		1.00	- .02	0	0	0	0
			- .07	0	0	0	0
			+ .05	0	0	0	0

APPENDIX B: BURNER NAME PLATE DATA

TABLE B1

Burner Type	Retention Head		Standard Head	
Manufacturer	Aero	Anthes	Terry	Beckett
Model No.	F-AFC-208	55J01D103	A1	S
Motor				
Speed (rpm)	1725	1725	1725	1725
Horsepower	1/8	1/8	1/8	1/8
Firing Range US gph	0.5 - 1.75*	0.65 - 1.00	0.75 - 1.25	0.5 - 3.0
Nozzle Type	80°	N.S.	N.S.	70° Solid
Oil Pump: Maker	Inglis	Inglis	Inglis	Sundstrand
Model	J2-CB-100-3	J2-CB-100-3	J3-CB-200-3	J2-BB-300-3

*These burners require different retention heads to cover the firing range quoted.

NS = Not Specified

APPENDIX C: METHODS OF SMOKE MEASUREMENT

Carbon, generated as soot in combustion systems, is evidence of inadequate mixing within the flame unless the excess-air level is close to or below the stoichiometric ratio for the fuel. The presence of soot particles at flame temperatures gives rise to the yellow-orange colour of the majority of domestic heating flames.

Soot particle sizes are small, <100A°, and the concentration is low, <20 mg/nm^3. Consequently, soot concentrations are not measured by conventional solid sampling techniques other than in applications where sampling time is of no consequence and the on/off cycling of the equipment can be controlled.

The use of qualitative or semi-quantitative methods of measuring the smoke emission from burners under standard conditions has been internationally widespread to the point where they are now the usual smoke measurements recommended in a national or technical standards e.g. CSA* or DOBETA**.

These qualitative methods are based on a visual or photometric comparison of the stain with a series of standard stains. The sample stain is produced on a standard filter paper by soot collection during the passage of a constant volume of flue gas. The advantages of this type of measurement are its simplicity and short sampling time both of which have lead to its widespread field use.

The Shell Bacharach Smoke Spot Meter

In this hand operated instrument a fixed volume of flue gas is drawn through a prepared filter paper by manual operation of a pump. The duration of each pump stroke is nominated as "slow" taking approximately four seconds; ten strokes are required per sample. The smoke spot is then compared with a standard Bacharach scale which extends from 0 to 9 (roughly equivalent to 0-1 Ringleman).

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*Canadian Standars Association

**Domestic Oil Burning Engineering Test Association

The smoke spot meter is recommended for use in CSA Standard B140.0 (1972) for"steady running" measurements. It is incapable of following changes in the smoke concentration in the combustion products during start-up and shut-down cycles.

The Von Brand Continuous Smoke Meter

In this continuous measuring instrument flue gas is withdrawn at a fixed sampling rate and passed through a moisture trap before being drawn through a prepared, moving, filter tape. The exposed area of filter tape is controlled by use of a small pre-cut aperture and the dust collector is maintained above the water dewpoint in an electrically heated block. Both the tape speed and the sampling rate can be varied allowing calibration of the instrument against the Bacharach scale. Measurement of the smoke number can be made visually (by comparison with a Bacharach scale) or automatically with calibrated reflectometer. This unit and others of similar type are capable of following changes in the smoke concentration in the combustion products and are suitable for use in assessing start-up and shut-down performance.

Smoke Number and Soot Emission: Steady Running Conditions

It has been stated that for distillate fuels the smoke number can be related to the entrained collected solids weight or gas stream soot concentration. Of the alternative correlations shown in Figure 2, that due to Hunt and Biller[1] is considered to be the most reliable.

It is important to realize that both of the above measurement techniques (which are used at CCRL as part of the OHA Clean Air Program) measure a smoke stain which is related to a volume of air at standard conditions. They do not consider the total mass of solid emitted to the atmosphere which is an additional function of the excess-air level and the fuel firing rate as can be seen in Figure 3.

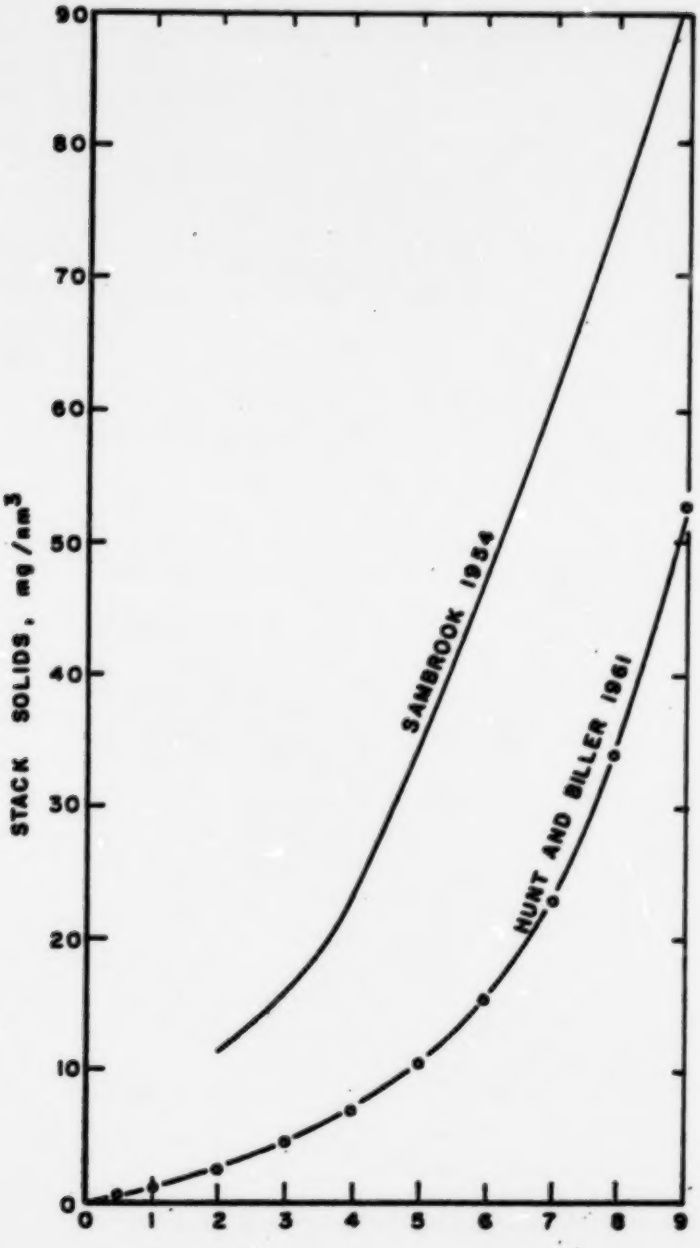


Figure 2. The relationship between Shell Bacharach Smoke Number and gas stream solids loading.

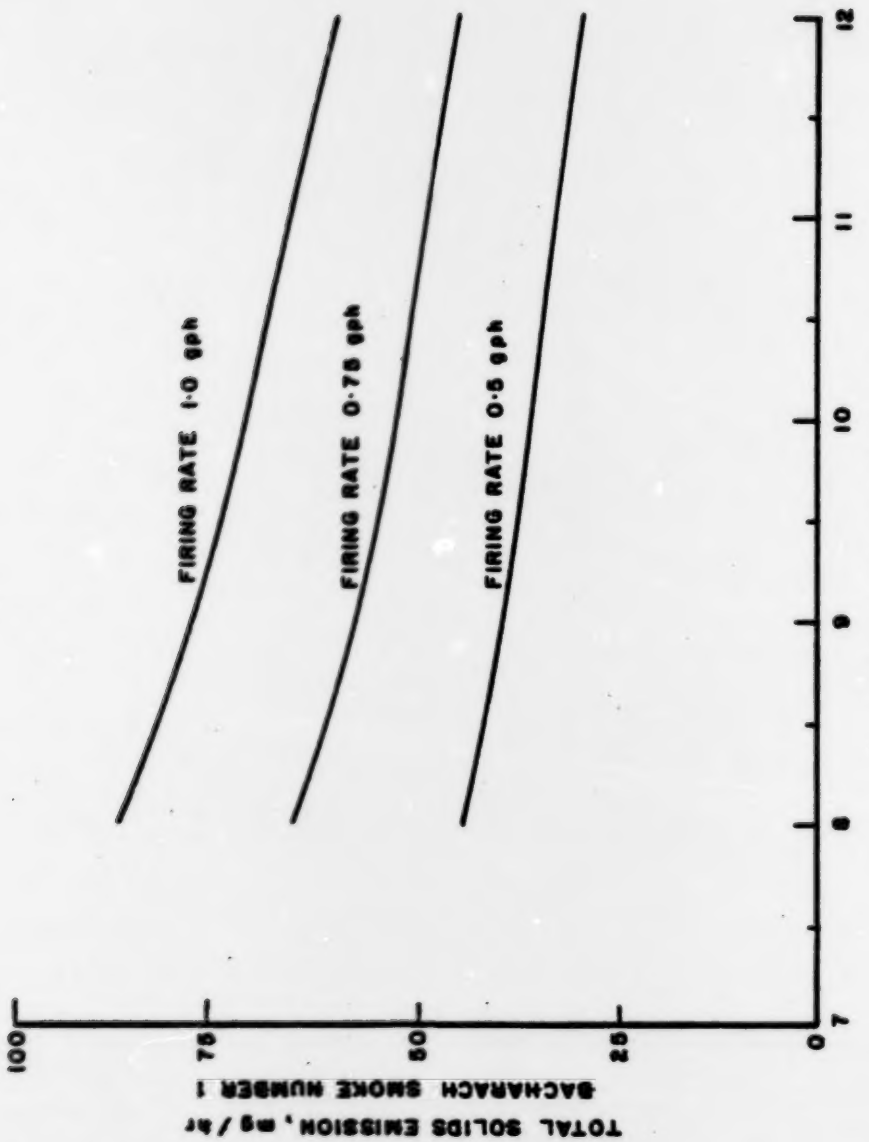


Figure 3. The effect of excess-air level and firing rate on solid emission at constant Smoke Number = 1.

The use of smoke numbers in assessment of the pollution potential of oil burning equipment is therefore subject to limitations additional to those imposed by the accuracy of the method. Fortunately, the sub-micron size of soot generated in distillate fuel combustion means that isokinetic sampling is not a necessity.

Comparison of the Cyclic Performance of Burners

A correlation between soot emission and Bacharach smoke number during individual start-up and shut-down cycles dpends directly on the accuracy with which the chimney flow is known throughout the cycle. The operations during an ignition sequence allow incomplete combustion (soot formation) during the establishment of a flame whilst the combustion air is increasing to a maximum when the full motor speed is developed. The calculation of a true solids emission therefore involves the integration of the smoke concentration with time and the integration of the volume flow rate with time; similarly on shut-down a double integration is required.

To overcome the difficulties associated with the variable flow through the system and to permit comparisons of start-up and shut-down performance to be made it is general practice to ignore the variations in mass flow through the furnace and to base assessments only on the measured smoke stain. Using these techniques it is possible to compare burners but it is not possible to calculate realistic smoke emissions.

The methods of assessment are all based on different analyses of the stain produced in a continuous sampling smoke meter of the Von Brand type.

Mean Smoke Number

The smoke number obtained is measured at suitable time intervals over the entire period during which the smoke number is above a reference number. The sum of these smoke numbers divided by the number of time intervals gives the mean smoke number; graphically - for a reference smoke number of zero - the calculation is equivalent to dividing the area under the smoke

number curve by the duration of smoke generation. It can be seen in Figure 4 that this mean smoke number does not place the different smoke curves in the correct order of performance which a direct measure of the area under the smoke number curve would.

Smoke Index

The method of comparison between burners adopted in the DOBETA performance standards[2] differs in its analysis of the smoke number/time curve. For an experimental tape speed of 2 in. per minute the smoke number is measured at 1/8 in. intervals over the entire period during which the smoke number is above 2. The sum of all these such numbers, measured from zero, is then divided by 16 to give a number reported as the Smoke Index.

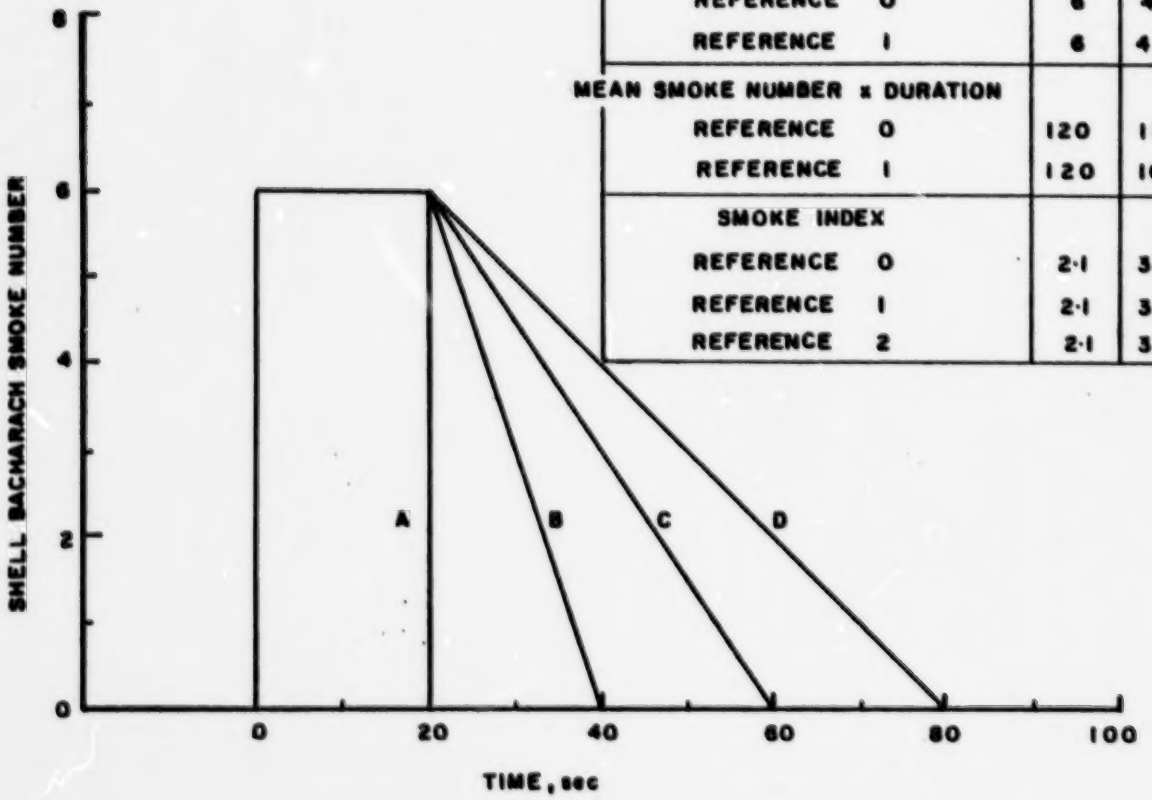
A reference smoke number of 2 was selected because it is the maximum specified in DOBETA standards for steady state operation. One advantage of the Smoke Index is that it is naturally weighted in favour of burners which generate smoke for less than one minute.

A calculation of Smoke Index based on the DOBETA procedure has been adopted in this report.

TEST PROCEDURES

A series of three-start-up and shut-down test cycles were carried out using the four low-speed-motor burners (see Appendix B). During each cycle smoke samples were continuously withdrawn and fed to the Von Brand smoke meter operating at a standard tape speed of 2 in. per minute. The reflectance of the smoke stain was measured with a standard reflectance head which had been calibrated to give a result as a smoke number.

The smoke number was measured at 1/10 in. intervals and the sum of the invividual smoke numbers (measured during the time when the smoke number was above 1) was divided by 20 to give a number reported as the Smoke Index. The smoke indices calculated in this manner are reported in Appendix A.



	A	B	C	D
MEAN SMOKE NUMBER				
REFERENCE 0	6	4·8	4	3·78
REFERENCE 1	6	4·9	4·8	4·3
MEAN SMOKE NUMBER x DURATION				
REFERENCE 0	120	180	240	300
REFERENCE 1	120	163	213	262
SMOKE INDEX				
REFERENCE 0	2·1	3·15	4·14	5·15
REFERENCE 1	2·1	3·135	4·08	5·07
REFERENCE 2	2·1	3·075	3·92	4·86

Figure 4. Analysis of the smoke number/time curves.

Simultaneous measurements of transient carbon monoxide concentrations were measured during the start-up and shut-down cycles using an infrared gas analyser. The peak concentrations are reported in Appendix A.

A series of tests to establish any difference that could be ascribed to pump performance were carried out. All pumps were tested using the same burner (Terry) over a series of three start-up and shut-down cycles and the results analysed as described above. The smoke indices calculated in this manner are reported in Appendix A.

REFERENCES

1. Hunt and Biller, API Conference on Distillate Fuel Combustion, Paper 61-6, 1961.

2. DOBETA Approvals Manual. Test Method 1: Determination of Smoke Number and Smoke Index.